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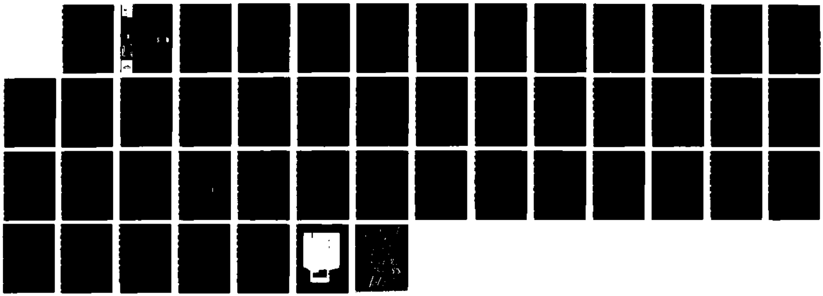

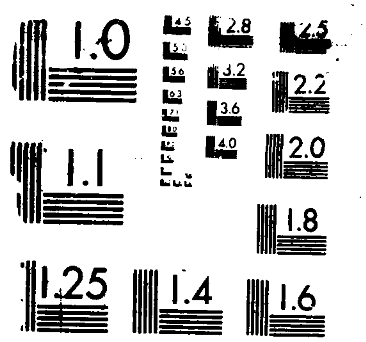

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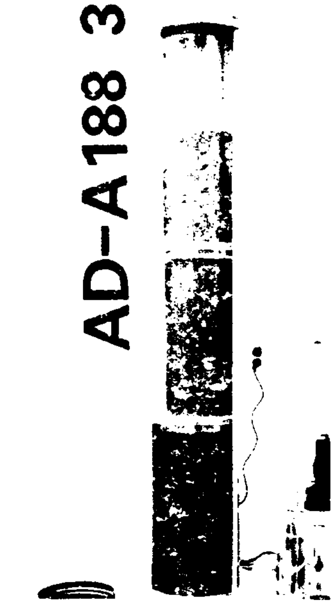

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TECHNICAL REPORT GL-87-25

COMPARATIVE EVALUATION OF 10-LB SLIDING WEIGHT AND SLEEVE-TYPE MANUAL COMPACTION RAMMERS FOR PAVEMENT DESIGN AND QUALITY CONTROL APPLICATIONS

by

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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

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17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

A study was conducted to compare results of laboratory compaction and CBR tests performed with 10-lb sliding weight and sleeve-type compaction rammers on 14 soils and one cement stabilized soil. All materials were compacted using the CE-55 compaction effort and 6-in.-diam molds. Parameters compared were maximum dry density, optimum water content, and soaked CBR. Test data were statistically analyzed using linear regression analyses and significance tests for difference in means with Student's t-distribution. Results of the statistical analyses indicated that there was no significant difference between values of maximum dry density, optimum water content, and CBR obtained with either rammer. Operator observations did reveal difficulty of soil binding in the sleeve rammer in 8 of the 15 materials compacted. Recommendations include allowing use of the sleeve-type rammer in laboratory tests on soils for military pavement design.

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18. SUBJECT TERMS (Continued).

California Bearing Ratio	Density	Optimum water content
CBR	Hammers	OWC
Compaction	Laboratory Compaction	Rammers

PREFACE

This investigation was sponsored by Headquarters, Office, Chief of Engineers (OCE) under Operation and Maintenance, Army funding. The project was conducted under the Facilities Investigation and Studies Program. The Technical Monitor for this investigation was Mr. A. Muller, DAEN-ECE-G.

The study was conducted by personnel of the Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES), under the general direction of Dr. W. F. Marcuson III, Chief, GL, and Mr. Harry H. Ulery, Chief, Pavement Systems Division, GL, WES. Principal Investigator was Dr. W. N. Brabston. Technicians actively involved in the study were Messrs. William J. Harper (formerly with WES) and Rodgers L. Coffing, Jr., and Mrs. Marie D. Alexander. This report was prepared by Dr. Brabston and edited by Mrs. Joyce Walker, Information Products Division, Information Technology Laboratory.

COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
foot-pounds (force)	1.355818	metre-newtons or joules
inches	2.54	centimetres
pounds (force)	4.448222	newtons
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

COMPARATIVE EVALUATION OF 10-LB SLIDING WEIGHT AND SLEEVE-TYPE MANUAL COMPACTION RAMMERS FOR PAVEMENT DESIGN AND QUALITY CONTROL APPLICATIONS

PART I: INTRODUCTION

Background

1. US Army Corps of Engineers' (CE) procedures for development of field specifications for rigid and flexible road and airfield pavements require determination of the maximum dry density and optimum water content for base and subbase course materials and for subgrade soils in fills. For flexible pavement design, the California Bearing Ratio (CBR) of the various materials is also required. Laboratory procedures for determining these values are specified in Military Standard MIL-STD-621A (Headquarters, Department of Defense 1964). Method 100 of this standard specifies procedures for conduct of moisture-density tests, and method 101 provides procedures for conducting the CBR test. Both methods specify that soils be compacted in a 6-in.-diam* cylinder mold using a 10-lb sliding weight-type compaction rammer (Photo 1a).

2. For pavement design, soils are molded using the CE-55 compaction effort. This effort requires that the soil be compacted in the mold in five separate layers with each layer receiving 55 blows of the 10-lb rammer falling 18 in. Based on an effective specimen height of 4.6 in. before trimming, the resulting energy expenditure for five layers is approximately 55,000 ft·lb/cu ft. Soil density and water content are determined directly from the molded soil specimen. CBR values are determined from CBR tests conducted on the compacted specimen in the mold after a 4-day soaking period. This CBR value is known as the soaked CBR.

3. The American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO) also have similar test methods. ASTM (1978) test method D-1557 and AASHTO (1982) test method T-180 have test procedures comparable to MIL-STD-621A, Method 100, for conducting moisture-density tests. ASTM (1978) test method D-1883 and

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

AASHTO (1982) test method T-193 describe procedures for conducting the CBR test similar to MIL-STD-621A, method 101. Although the ASTM and AASHTO methods in general are similar to the MIL-STD-621 methods, one exception is the use in the ASTM and AASHTO methods of a 10-lb sleeve-type manual compaction rammer as opposed to the sliding weight rammer specified in MIL-STD-621 (Photo 1b).

4. Through general acceptance and use of ASTM, AASHTO, and other agencies' standards throughout the United States, the sleeve-type rammer has become the predominate type of apparatus used in compaction tests in most commercial and noncommercial soils laboratories. It appears that the primary agency currently specifying the sliding weight rammer is the CE.

5. This situation gave rise to the question that partially forms the basis of this investigation; that is, would it be appropriate for the CE to allow or specify use of the sleeve-type rammer in laboratory compaction tests involving soils and aggregate materials for pavement design. Current CE publications for civil works (Department of the Army, Office, Chief of Engineers 1970) specify the sliding weight rammer while military standards for military pavement design (Headquarters, Department of Defense 1964) specify the sliding weight rammer. In addition the tri-service technical manual for materials testing specifies in the text that a sliding weight rammer be used for laboratory compaction (Departments of the Army, Navy, and Air Force 1971). In view of the historical involvement of the sliding weight rammer in past studies pavement test sections from which current military pavement design criteria were empirically developed, the impact of allowing use of the sleeve-type apparatus in future laboratory compaction tests must be determined. Therefore, on that basis, this investigation was undertaken. The scope of this study was limited only to parameters involved in pavement design; i.e., maximum dry density, optimum water content, and soaked CBR.

Objective

6. The objective of this study was to determine whether a significant difference exists between values of maximum dry density, optimum water content, and soaked CBR determined from laboratory tests on soils compacted with 10-lb sliding weight and 10-lb sleeve-type manual compaction rammers using the CE-55 compaction effort and 6-in.-diam compaction molds.

Scope

7. The study was conducted as follows:

   a. Ten soils representative of materials used in pavement structures or as subgrade soils were selected for the study. The soil types ranged from fine-grained subgrade soils to granular base course materials with emphasis on granular materials.

   b. Moisture-density and soaked CBR tests were conducted on each soil following procedures indicated in MIL-STD-621-A, Methods 100 and 101, respectively. Two sets of specimens were molded at comparable water contents using the CE-55 compaction effort. One set was molded with the 10-lb sliding weight rammer and the second set with the 10-lb sleeve-type rammer.

   c. Moisture-density tests were also conducted on one of the granular materials that had been treated with portland cement to obtain a data point with a stabilized material.

   d. Additional moisture-density data obtained from a previously unreported Waterways Experiment Station (WES) laboratory study conducted under similar conditions on four granular soils were incorporated into the data base prior to analyses of the data.

   e. A statistical analysis was conducted on the 15 data sets using linear regression techniques and comparison of means for Student's t-distribution to determine whether there was significant difference between test results obtained with the two types of rammers.

Previous Studies

8. A number of different studies have been conducted comparing compaction results obtained with different types of manual and mechanical rammers. Of these, three investigations conducted at WES appear to be most relevant to this study.

9. Burns (1959) conducted a study to evaluate compaction results obtained with CE 10-lb sliding weight and ASTM 10-lb sleeve-type manual compaction rammers and with several types of mechanical rammers then in use by various CE division laboratories. The manual rammer comparisons involved three soils: a fat (plastic) clay (CH)*; a lean (silty) clay (CL); and a clayey gravel (GC). All soils were compacted using the modified AASHO compaction effort which is similar to CE-55 effort. For the 10-lb rammer and CE-55 effort, a 6-in.-diam mold is normally used. Burns reported, "Compaction

* Classified according to the Unified Soil Classification System (USCS).

curves developed with the two hammers are identical for the fat clay and clay-gravel material, and are in very close agreement for the lean clay soil with less than 1 lb per cu ft difference in the indicated modified AASHO maximum density."

10. After establishing an optimum water content for each soil, 10 specimens were molded with each type of rammer as close as possible to the optimum water content using the same compaction effort to evaluate reproducibility of results. Test results indicated a difference in mean dry density values obtained with the two rammers of 0.2, 0.6, and 0.6 lb/cu ft for the CH, CL, and GC materials, respectively.

11. One interesting observation made in this study concerning use of the sleeve rammer was that it was necessary to stop application of blows frequently and clean soil from the bottom of the rammer and from inside the sleeve particularly when compacting specimens on the wet side of optimum. If this had not been done, the report states, the rammer would have jammed in the sleeve or a lower density would have been obtained. This operational difficulty with the sleeve-type rammer has historically been one of the primary reasons for the use of the sliding weight rammer.

12. Durham and Hale (1977) conducted a study which involved comparing test results obtained with 5.5-lb sliding weight and sleeve-type manual compaction rammers using standard compaction effort. The standard effort involves compaction energy of approximately 12,375 ft-lb/cu ft. A cylindrical compaction mold 4 in. in diameter and 4.5 in. high was used in the study. Three soils were tested--two Vicksburg silty clay materials (ML and CL) and Vicksburg buckshot clay (CH). The former two materials and the latter material are similar to the CL and CH soils, respectively, tested in the study by Burns. One significant conclusion of the study was that test results obtained with the sleeve-type rammer indicated higher maximum dry density values and lower optimum water content values than those obtained with the sliding weight rammer. Differences in mean values of maximum densities and optimum water contents obtained with the two rammers were 2.0 lb/cu ft and 1.0 percent, respectively.

13. Horz (1983) conducted a study to evaluate results obtained with various types of manual compaction rammers. Included in the study were evaluations of the 10-lb sliding weight rammer specified in MIL-STD-621A and the 10-lb ASTM sleeve-type rammer. Five soils were evaluated in this portion of

the study--a plastic clay (CH), a lean and a silty clay (both CL), a silty sand (SM), and a gravelly clayey sand (SC). The CH and CL materials were Vicksburg buckshot and Vicksburg silty clay materials, respectively. All materials were compacted using a modified compaction effort similar to the CE-55 effort. All soils except the SC material were compacted in a 4-in.-diam mold. For this procedure, the soil was compacted in five layers with each layer receiving 25 blows with the 10-lb rammer. The SC material was compacted in a 6-in. mold in five layers, each receiving 56 blows of the 10-lb rammer. A conclusion of the study was that the 10-lb sliding weight-type rammer produced lower maximum dry density and higher optimum water content than the sleeve-type rammers. Test data indicated that the mean differences in maximum dry density and optimum water content values were 0.8 lb/cu ft and 0.2 percent, respectively.

PART II: EQUIPMENT, SOILS, AND TEST PROCEDURES

Equipment

Compaction rammers

14. A view of the 10-lb sliding weight rammer is shown in Photo 1a. This rammer is standard equipment specified in MIL-STD-621A to be used for laboratory compaction of soils for pavement design and quality control. The rammer has a 10-lb sliding weight which is dropped from a height of 18 in. onto a 2-in.-diam spring-cushioned steel foot which impacts on the soil. Fall path of the sliding weight is controlled by a 5/8-in.-diam guide rod. A view of the 10-lb sleeve-type rammer is shown in Photo 1b. This rammer conforms to requirements indicated in ASTM method D-1557 and AASHTO method T-180. The rammer consists of a 2-in.-diam 10-lb weight attached to a shaft that passes through the top of a hollow cylindrical guide sleeve. In compaction, the shaft-rammer unit is raised manually and dropped from a height of 18 in. so that the foot of the 10-lb weight impacts directly on the soil.

Mold

15. Soil specimens were compacted in a 6-in.-diam cylinder mold conforming to specifications indicated in MIL-STD-621A (Figure 1). The mold is 7 in. high with a collar extension approximately 2 in. high. A metal spacer disc, 5-15/16 in. in diameter and 2-1/2 in. thick is placed in the bottom of the mold during compaction. The compacted and trimmed specimen is thus 6 in. in diameter and 4-1/2 in. high.

Soils

16. Ten soil materials were selected for the study. Of these 10 materials, it was desired that two should meet gradation requirements for base courses and three meet gradation requirements for subbase courses, as specified in the tri-service manual (Departments of the Navy, the Army, and the Air Force 1978). The remaining soils were considered to be subgrade materials with emphasis on granular-type soils. One soil, in addition to being tested in the unbound state, was tested with 6 percent portland cement added prior to compaction to obtain a data point on stabilized soils. A listing of the various materials along with a description of each one is given in Table 1.

Gradation curves and classification data for these materials are shown in Figures 2-5. As can be seen from Table 1, the wide range of material types desired for the study was generally achieved. The Florida limerock, however, did not meet base course gradation requirements.

Test Procedures

Preparation of soils

17. The soil samples were first air-dried and then passed through a 3/4-in. and/or 1/4-in. sieve. For materials having particle size greater than 3/4 in., the +3/4-in. portion was removed and replaced with an equal amount of material that passed the 3/4-in. sieve but was retained on the 1/4-in. sieve. Soil and sand aggregations were broken down to pass the 1/4-in. sieve without degradation of actual aggregate particles. After initial determination of water content, an amount of water calculated to bring the sample to the desired water content was added to and thoroughly mixed into the soil, which was then sealed in a container and allowed to equilibrate for 24 hr. Generally, five samples were processed, each at a different water content, to provide a sufficient number of compacted specimens to adequately define the moisture density relations. If necessary, additional specimens were prepared to extend the data range to higher or lower water contents.

Compaction procedures

18. Next, one set of soil specimens was compacted in 6-in.-diam molds with a 10-lb sliding weight rammer following procedures indicated in MIL-STD-621A. For each molded specimen, the soil was compacted in five layers with each layer receiving 55 blows of the compaction rammer. As procedures indicate, the thickness of the soil layers was such that after compaction the total thickness of the specimen was between 4.6 and 5.1 in. After each specimen was compacted, the soil was carefully trimmed flush with the top of the mold. After compaction tests had been completed with the sliding weight rammer, a second set of soil specimens was compacted with the 10-lb sleeve-type rammer following similar procedures. To obtain specimens compacted with each rammer at comparable water contents, the same soil from any one container at a particular water content was used in both tests. To minimize water loss during the time lag between compaction with the two rammers, the container was maintained tightly sealed. In addition, prior to compaction with the sleeve

rammer, soil moisture content was monitored and any necessary adjustments were made to ensure that there was no large difference in the water contents of the specimens compacted with the two rammers using soil from the same container. One operator compacted all specimens. The operator was requested to note and record any difficulty encountered with either rammer.

Density and water content measurements

19. Wet density values were calculated directly from known weight of soil and volume of the mold. Water content values were determined from soil removed during trimming and from samples from the batched materials. This was done because the molded specimens were required intact for later determination of CBR values. Soaked CBR values were determined following procedures indicated in MIL-STD-621A. Prior to conduct of the CBR penetration test, the sample was immersed in water in the mold for a 4-day soaking period. During soaking, a 10-lb surcharge plate was positioned on top of the specimen. After soaking, the CBR penetration test was conducted directly on the specimen in the mold.

PART III: TEST RESULTS, PREVIOUS WORK, AND ANALYSES

Test Results

20. Results of the moisture-density and CBR tests are presented in Figures 6-16 as plots of dry density versus water content and CBR versus water content. Values of maximum dry density, optimum water content, and the associated CBR value are indicated in Table 2. Values of maximum dry density were determined in the conventional way, i.e. the density value indicated at the peak of the moisture-density curve. Optimum water content was taken as the water content associated with the maximum dry density. CBR values indicated in Table 2 are those values associated with the optimum water content as indicated on the CBR-water content plot. Also indicated in Table 2 are mean values of dry density, water content, and CBR for all test data and standard deviation from the mean; differences between the individual values obtained with the sliding weight rammer and those obtained with the sleeve-type rammer; and mean difference and standard deviation from the mean. Operator comments are also noted.

21. The test data indicate very close agreement between results obtained with each type of rammer. Difference in density values ranged from -1.2 to +2.4 lb/cu ft with a mean difference of +0.5 lb/cu ft and a standard deviation of 1.0 lb/cu ft. Of 11 pairs of test data, sleeve rammer densities were higher than sliding weight rammer densities in six cases, lower in two cases, and there was no difference in density values in three cases. Differences in optimum water content ranged from -1.1 to +1.4 percent with a mean difference of 0.2 percent and standard deviation of 0.7 percent. Optimum water content values obtained with the sleeve rammer were lower than those obtained with the sliding weight rammer in two cases, higher in seven cases, and equal in two cases. In two cases, clayey sand (soil No. 3) and buckshot clay (soil No. 6), sleeve rammer densities were higher and optimum water contents were lower than values obtained with the sliding weight rammer. Values of CBR indicated differences ranging from -11 to +39 with a mean difference of 7.6 and standard deviation of 15.2. CBR values obtained with the sleeve rammer were higher than those obtained with the sliding weight rammer in seven cases and lower in three cases.

22. Operator comments indicate that the operator encountered difficulty with soil binding in the sleeve rammer with 6 of the 11 materials; however, the cement stabilized gravel (soil No. 11) and the clayey gravel (soil No. 5) were the same basic soils.

Previous Work

23. Data were also available from a similar investigational effort previously conducted, but not reported, at WES. These tests were conducted by another operator. The work involved conducting compaction tests on four granular materials to compare results obtained with the 10-lb sliding weight and 10-lb sleeve-type compaction rammers similar to this study. Procedures followed and equipment used were identical to those in this study, i.e. MIL-STD-621A Method 100 and the two rammers, except that no CBR tests were conducted. The four soils involved in the study are described in Table 3. Gradation and classification data for these materials are shown in Figure 17. The materials are indicated as soils 12 through 15 in Table 3 and Figure 17. Test results, presented as plots of dry density versus water content are shown in Figures 18-21. Values of maximum dry density and optimum water content are shown in Table 4 along with mean values, difference in individual values obtained with each rammer, mean differences, and standard deviations. It should be noted that the maximum dry density values for the limestone were estimated since there was no peak in the moisture-density plot for that material. Operator comments are also indicated in Table 4.

24. The data in Table 4 indicate that differences between the densities obtained with the sliding weight rammer and those obtained with the sleeve rammer ranged from -0.2 to +0.4 lb/cu ft with a mean value of +0.2 lb/cu ft. Standard deviation was 0.3. Sleeve rammer densities were higher in two cases, lower in one case, and equal in one case. Differences in optimum water content ranged from -0.6 to +0.4 percent with a mean value of -0.1 percent. Standard deviation was 0.4. Optimum water content values were lower for the sleeve rammer data in three cases and higher in one case. In two cases, clean sand (soil No. 12) and limestone (soil No. 15), the sleeve rammer density was higher and the optimum water content was lower than the sliding weight rammer data.

25. Operator comments indicate that there was difficulty with soils binding in the sleeve rammer for the gravelly sand (soil No. 13) and the gravelly clayey sand (soil No. 14).

Statistical Analyses

Linear regression

26. All data from both groups of tests are summarized in Table 5. Least squares linear regression analyses were conducted on the maximum dry density, optimum water content, and CBR data pairs. The combined data base yielded 15 data pairs for the density and water content data and 10 data pairs for the CBR data. In the regression analyses, the sliding weight rammer data were the dependent variables and the sleeve rammer data were the independent variables. The general linear regression equation is:

$$Y = a_0 + a_1 X$$

where

Y = dependent variable

a_0 = intercept

a_1 = slope

X = independent variable

Results of the linear regression analyses are given in the tabulation below.

Data Source	Units	n	Sliding Weight Rammer Mean	Sliding Weight Rammer Standard Deviation	Sleeve-Type Rammer Mean	Sleeve-Type Rammer Standard Deviation	a_0	a_1	R^2*
Maximum dry density	pcf	15	123.0	14.0	123.4	13.7	-3.166	1.023	0.99
Optimum water content	percent	15	8.8	4.6	8.9	4.5	-0.207	1.011	0.98
CBR	-	10	67.5	39.1	75.1	40.8	0.743	0.889	0.86

* R^2 = Correlation coefficient.

Results of the linear regression analyses indicate excellent correlations for the paired maximum dry density and optimum water content data sets as

evidenced by (a) values of the slope coefficient approaching unity, (b) low values of the intercept coefficient, and (c) very high value of the correlation coefficient. Good correlations were also obtained with the CBR data; however, for several data pairs, differences between CBR values obtained with the two rammers were large.

Significance tests

27. An analysis of difference in means for paired samples with Student's t-distribution was also conducted. Student's t-distribution was assumed because of the small number of data pairs involved ($n < 30$). For this analysis, the null hypotheses H_0 is: there is no difference in the mean values of the paired data sets, i.e.,

$$H_0: \mu_1 = \mu_2$$

where

μ_i = means of the data sets

The alternative hypotheses H_1 is: there is a difference in means, i.e.,

$$H_1: \mu_1 \neq \mu_2$$

The null hypothesis is rejected if the absolute value of the test statistic t computed from the experimental data is greater than the t-value determined from standard t-tables for the desired level of significance α for the degrees of freedom dictated by the size of the data base, $(n-1)$. The table t-value is generally designated $t_{\alpha,n-1}$. For these data, a significance level (risk of erroneously rejecting the null hypothesis) of 0.05 was selected. For the density and water content data $t_{.05,14} = 2.145$; for the CBR data, $t_{.05,9} = 2.262$.

28. Results of the significance tests are as follows.

Data Source	Test Statistic t	$t_{\alpha,\ n-1}$	t vs $t_{\alpha,\ n-1}$	Conclusion on Null Hypothesis
Maximum dry density	1.63	2.145	1.63 < 2.145	Cannot reject
Optimum water content	0.70	2.145	0.70 < 2.145	Cannot reject
CBR	1.59	2.262	1.59 < 2.262	Cannot reject

These results indicate that for all three data sets the test statistic is less than the table statistic and, therefore, the null hypotheses cannot be rejected. Thus, it may be concluded that there is no significant difference between the mean values of maximum dry density, optimum water content, and CBR obtained with the two compaction rammers.

PART IV: DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Discussion

29. A review of the test results and statistical analyses of the data in this study indicates no significant difference between mean values of maximum dry density, optimum water content, and CBR data obtained with either the sliding weight or the sleeve-type compaction rammers. The results agree with those found in the study by Burns (1959) which involved three soils, two of which were similar to those used in this investigation, i.e., Buckshot clay and Vicksburg lean clay. The procedures and equipment used in the Burns study were also similar to those used in this investigation, i.e., similar compaction rammers and 6-in.-diam molds. Results of this test did not agree with the findings by Durham and Hale (1977) reported in a study which also involved Buckshot clay and two Vicksburg silty clays. However, in their study, standard compaction effort was applied using 5.5-lb rammers and 4-in.-diam molds. The results of this study also do not agree with the findings by Horz (1983) which also involved Buckshot clay and Vicksburg silt clay. In the Horz study on five soils, modified compaction effort was applied and 10-lb rammers were used; however, four of the soils were compacted in 4-in.-diam molds and one soil was compacted in a 6-in.-diam mold. Of the 15 materials analyzed in this study, there were only four cases (soils 3, 6, 12, and 14, Table 5) in which the sleeve rammer results indicated both higher maximum density and lower optimum water content--a combination necessary to demonstrate separate and distinct compaction curves. A review of the compaction curves for these materials (Figures 8, 11, 18, and 20) indicates that in only two cases (Figure 11 and Figure 20) are the compaction curves for the sleeve rammer clearly shifted to the left and above the curves for the sliding weight-type rammer. Respective soils involved were buckshot clay (CH) and a gravelly clayey sand (SP-SL). The absence of evidence of significant difference in test results with the two rammers indicated in this study and the one by Burns (1959) and the opposing conclusions found in the studies by Durham and Hale (1977) and by Horz (1983) suggest that the difference in findings might be because of the use of different equipment, i.e., mold size and rammer configuration even though the calculated energy input values were approximately equal.

30. Test results on the Buckshot clay (from this study and from those by Durham and Hale and by Horz) suggest, however, that, for a highly plastic material, use of different compaction rammers or procedures (i.e., rammer and mold) might possibly yield distinctly different compaction curves. Certainly, no conclusion can be reached from the data available, and test results on the same soil do not concur (Burns 1959). The study reported herein was directed toward granular materials and did not involve the more plastic soils to any significant degree. Therefore, it would appear that a similar study involving a significant number of moderately to highly plastic soils possibly should be undertaken in the future.

31. As noted, this investigation primarily involved granular soils. Therefore, test results for the CBR data exhibited more variation and scatter than did those for the density or water content data. Such variation is common with granular materials, particularly those with larger particle sizes. For these materials, reproducibility of CBR test results is often difficult. It should also be noted that the scope of this study did not permit replication because of the large number of soils involved. However, it was recognized that the use of single-point comparisons of random variables, particularly those that exhibit a wide frequency distribution such as CBR values for granular soils, could involve some difficulty in data interpretation.

32. One important result of this investigation was the report of difficulties encountered by the two operators with soil binding in the sleeve rammer during compaction. This phenomenon was evident for 8 of the 15 soils involved (soils 3, 5, 7, 9, 10, 11, 13, and 14, Table 5). This problem was also noted by Burns in his report. There appears to be no specific correlation between soil characteristics and whether difficulty was encountered. For the soils with which binding was experienced, an examination of gradation and classification data (Figures 3, 4, 5, and 17) indicates the plasticity index (PI) ranged from nonplastic (NP) to 17 and the fines content (percent < 0.074 mm) ranged from 3 to 100 percent. Thus, it is obvious that for any type soil, the operator must exhibit extreme care when using the sleeve device and take necessary precautions to ensure that the interior of the sleeve is free from soil particles that would cause binding and possibly invalidate test results.

Conclusions

33. The following conclusions are made based on the work and data analyses conducted under this investigation and on work by other investigators reported herein.

   a. There is no significant difference between the values of maximum dry density, optimum water content, and CBR obtained on soils compacted with the 10-lb sliding weight and 10-lb sleeve rammers for the CE-55 compaction effort with 6-in.-diam compaction molds.

   b. There is evidence to indicate that the use of a 4-in.-diam mold for laboratory soil compaction may yield test results different from those obtained with a 6-in.-diam mold.

   c. When using the sleeve-type rammer, there is considerable potential for soil to bind between the interior sleeve wall and the side of the rammer foot which could result in invalid or erroneous test results.

   d. Although there is no conclusive evidence, the test data do suggest the possibility that results of compaction tests on highly plastic soils may differ with rammer type.

Recommendations

34. The following recommendations are made based on the results of this study.

   a. Allow the use of the 10-lb sleeve-type rammer (often referred to as the 10-lb ASTM rammer) in the laboratory compaction of soils for military pavement design only; however, when the soil is compacted in a 6-in.-diam mold allow the use of the CE-55 compaction effort.

   b. Make the operator thoroughly aware, under the conditions indicated in a above, of the necessity of maintaining the device in such a condition as to prevent binding of soil in the sleeve.

   c. Undertake a study to investigate the effect of the use of different compaction procedures at the same compaction energy level on test results. The study should include the use of 5.5- and 10-lb rammers and 4- and 6-in.-diam molds for the CE-12 (standard) and CE-55 (modified) compaction energy levels. Because of the inclusion of the 4-in.-diam mold, only sandy and fine-grained soils should be investigated.

   d. Undertake an adjunct study to the one recommended in c to include only highly plastic soils.

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Table 1

Description of Soil Types

Soil No.	Nomenclature	USCS Classification	Description
1	Crushed limestone	GW	Graded crushed limestone aggregate--met gradation requirements for 100 CBR base course except below-specification on the No 10 sieve.
2	Limerock	SM	Crushed Florida limerock--the sample did not meet base course requirements due to poor grading.
3	Clayey sand	SP-SC	A local pit-run gravel--met grading requirements for 40 CBR subbase course.
4	Pea gravel	GP	A local washed aggregate of uniform size (95 percent 1/4-1/2 in.)--met grading requirements for 50 CBR subbase course.
5	Clayey gravel	GP-GC	A blend of local pit and washed gravels designed to obtain the indicated gradation--met gradation requirements for 50 CBR subbase course.
6	Buckshot clay	CH	A highly plastic local alluvial clay--subgrade material.
7	Silty clay	CL	Vicksburg loess--subgrade material.
8	Yuma sand	SP-SM	A nonplastic sand material from Yuma, Arizona--subgrade material.
9	Sand buckshot blend	SM-SC	A mixture of silty sand with some buckshot clay--subgrade material.
10	River sand blend	SM	A blend of silty sand and coarse-grained river sand--subgrade material.
11	Cement stabilized gravel	GP-GC	Clayey gravel (No 5) stabilized with 6 percent portland cement.

Table 2

Summary of Dry Density, Optimum Water Content, and CBR Test Results

Soil No.	Description	USCS Class	Maximum Dry Density: Sliding Weight Rammer	Maximum Dry Density: Sleeve Rammer	Maximum Dry Density: Difference	Optimum Water Content: Sliding Weight Rammer	Optimum Water Content: Sleeve Rammer	Optimum Water Content: Difference	CBR: Sliding Weight Rammer	CBR: Sleeve Rammer	CBR: Difference	Operator Comments
1	**Crushed limestone**	GW	130.0	131.5	+1.5	2.0	2.5	+0.5	89	100	+11	
2	**Limerock**	SM	113.0	113.0	0	13.2	13.7	+0.5	119	108	-11	
3	**Clayey sand**	SP-SC	132.9	133.0	+0.1	6.7	6.1	-0.6	97	93	-4	Soil binds in sleeve rammer
4	**Pea gravel**	GP	100.5	102.9	+2.4	2.8	3.0	+0.2	46	85	+39	
5	**Clayey gravel**	GP-GC	133.9	133.7	-0.2	5.5	5.5	0	118	135	+17	Soil binds in sleeve rammer
6	**Buckshot clay**	CH	107.7	108.5	+0.8	17.8	16.7	-1.1	1.8	2.1	+0.3	
7	**Silty clay**	CL	111.0	111.0	0	14.8	14.9	+0.1	53	45	-8	Soil binds in sleeve rammer
8	**Yuma sand**	SP-SM	101.9	102.1	+0.2	13.1	14.5	+1.4	23	25	+2	
9	**Sand-buckshot blend**	SM-SC	131.6	131.6	0	6.4	6.4	0	74	95	+21	Soil binds in sleeve rammer
10	**River sand blend**	SM	126.5	127.6	+1.1	6.6	6.7	+0.1	54	63	+9	Soil binds in sleeve rammer
11	**Cement stab. gravel**	GP-GC	132.3	131.1	-1.2	7.0	8.0	+1.0	-	-	-	Soil binds in sleeve rammer
Mean			120.1	120.6	+0.5	8.7	8.9	+0.2	67.5	75.1	7.6	
Standard Deviation			13.3	13.0	1.0	5.2	5.1	0.7	39.1	40.8	15.2	

Table 3

Description of Soils in Previous Study

Soil No.	Nomenclature	USCS Classification	Description
12	Clean sand	(SP)	A local washed concrete sand--met requirements for 30 CBR subbase course.
13	Gravelly sand	(SP)	Local pit-run gravel material--met requirements for 40 CBR subbase course.
14	Gravelly clayey	(SP-SC) sand	Local pit-run gravel material--met grading requirements for 40 CBR subbase course.
15	Limestone	(GP)	Graded crushed limestone--met grading requirements for 100 CBR base course.

Table 4

Summary of Dry Density, Optimum Water Content, and CBR Test Results

Other Work

Soil No.	Description	USCS Class	Maximum Dry Density: Sliding Weight Rammer	Maximum Dry Density: Sleeve Rammer	Maximum Dry Density: Difference	Optimum Water Content: Sliding Weight Rammer	Optimum Water Content: Sleeve Rammer	Optimum Water Content: Difference	Operator Comments
12	Clean sand	SP	113.4	113.8	+0.4	13.1	13.0	-0.1	
13	Gravelly sand	SP	129.1	128.9	-0.2	9.6	9.0	-0.6	Soil binds in sleeve rammer
14	Gravelly clayey sand	SP-SC	132.8	133.2	+0.4	7.4	7.3	-0.1	Soil binds in sleeve rammer
15	Limestone	GP	148.7	148.7	0	5.5	5.9	+0.4	
Mean			131.0	131.2	+0.2	8.9	8.8	-0.1	
Standard Deviation			14.5	14.4	0.3	3.3	3.1	0.4	

Table 5

Summary of Dry Density, Optimum Water Content and CBR Test Results

Soil No.	Description	USCS Class	Maximum Dry Density			Optimum Water Content			CBR			Operator Comments
			Sliding Weight Rammer	Sleeve Rammer	Difference	Sliding Weight Rammer	Sleeve Rammer	Difference	Sliding Weight Rammer	Sleeve Rammer	Difference	
1	Crushed limestone	GW	130.0	131.5	+1.5	2.0	2.5	+0.5	89	100	+11	
2	Limerock	SM	113.0	113.0	0	13.2	13.7	+0.5	119	108	-11	
3	Clayey sand	SP-SC	132.9	133.0	+0.1	6.7	6.1	-0.6	97	93	-4	Soil binds in sleeve rammer
4	Pea gravel	GP	100.5	102.9	+2.4	2.8	3.0	+0.2	46	85	+39	
5	Clayey gravel	GP-GC	133.9	133.7	-0.2	5.5	5.5	0	118	135	+17	Soil binds in sleeve rammer
6	Buckshot clay	CH	107.7	108.5	+0.8	17.8	16.7	-1.1	1.8	2.1	+0.3	
7	Silty clay	CL	111.0	111.0	0	14.8	14.9	+0.1	53	45	-8	Soil binds in sleeve rammer
8	Yuma sand	SP-SM	101.9	102.1	+0.2	13.1	14.5	+1.4	23	25	+2	
9	Sand-buckshot blend	SM-SC	131.6	131.6	0	6.4	6.4	0	74	95	+21	Soil binds in sleeve rammer
10	River sand blend	SM	126.5	127.6	+1.1	6.6	6.7	+0.1	54	63	+9	Soil binds in sleeve rammer
11	Cement stab. gravel	GP-GC	132.3	131.1	-1.2	7.0	8.0	+1.0	-	-	-	Soil binds in sleeve rammer
12	Clean sand	SP	113.4	113.8	+0.4	13.1	13.0	-0.1	-	-	-	
13	Gravelly sand	SP	129.1	128.9	-0.2	9.6	9.0	-0.6	-	-	-	Soil binds in sleeve rammer
14	Gravelly clayey sand	SP-SC	132.8	133.2	+0.4	7.4	7.3	-0.1	-	-	-	Soil binds in sleeve rammer
15	Limestone	GP	148.7	148.7	0	5.5	5.9	+0.4	-	-	-	
Mean			123.0	123.4	+0.4	8.8	8.9	+0.1	67.5	75.1	7.6	
Standard Deviation			14.0	13.7	0.8	4.6	4.5	0.6	39.1	40.8	15.2	

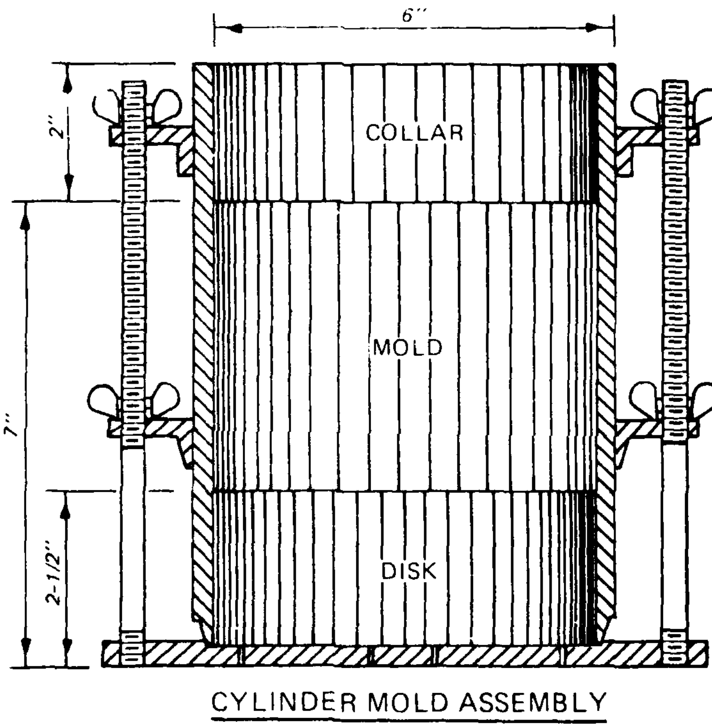
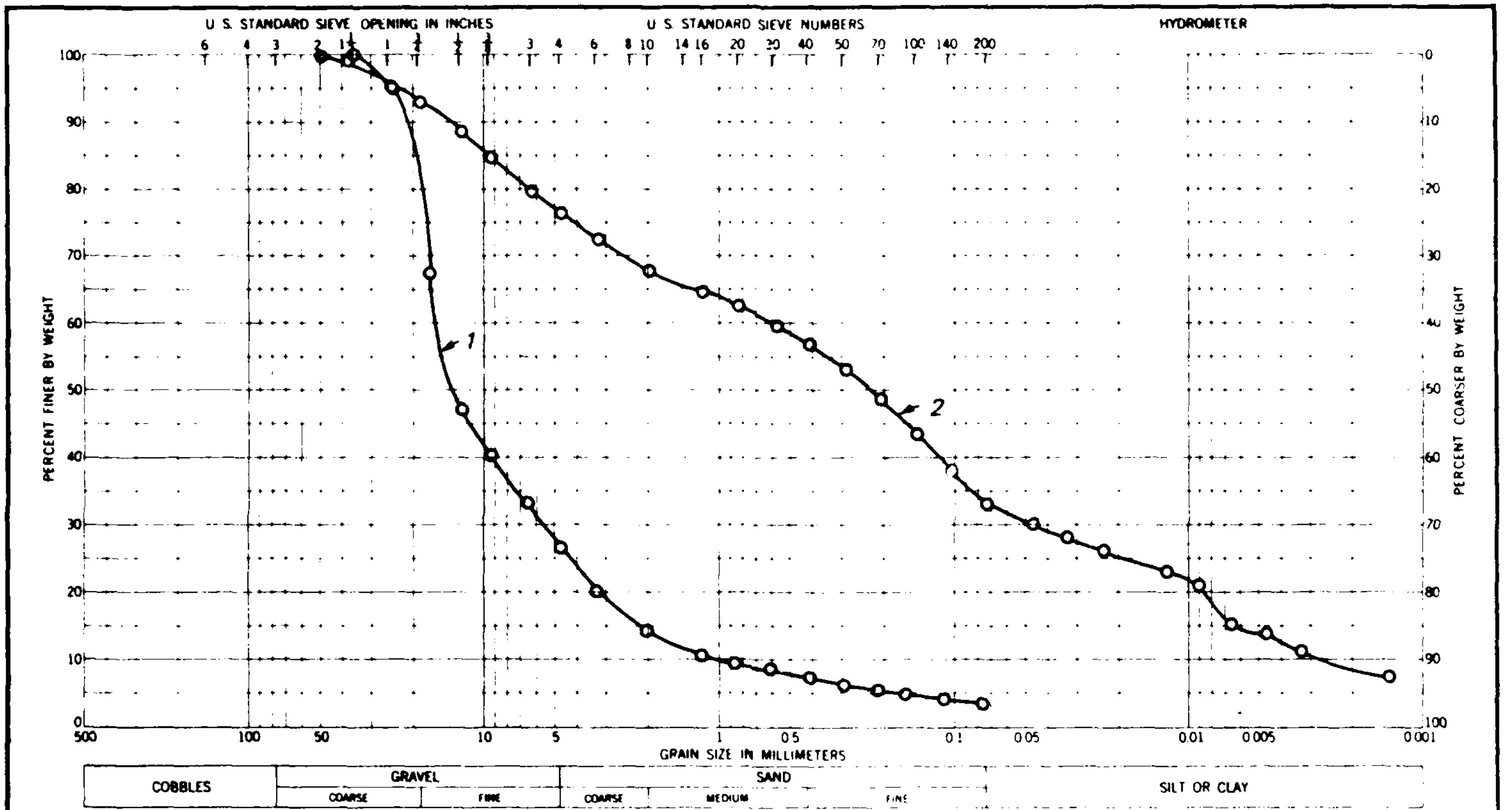


Figure 1. Six-in.-diam compaction mold



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI
1		CRUSHED LIMESTONE (GW)				NP
2		LIMEROCK (SM)		17	14	3

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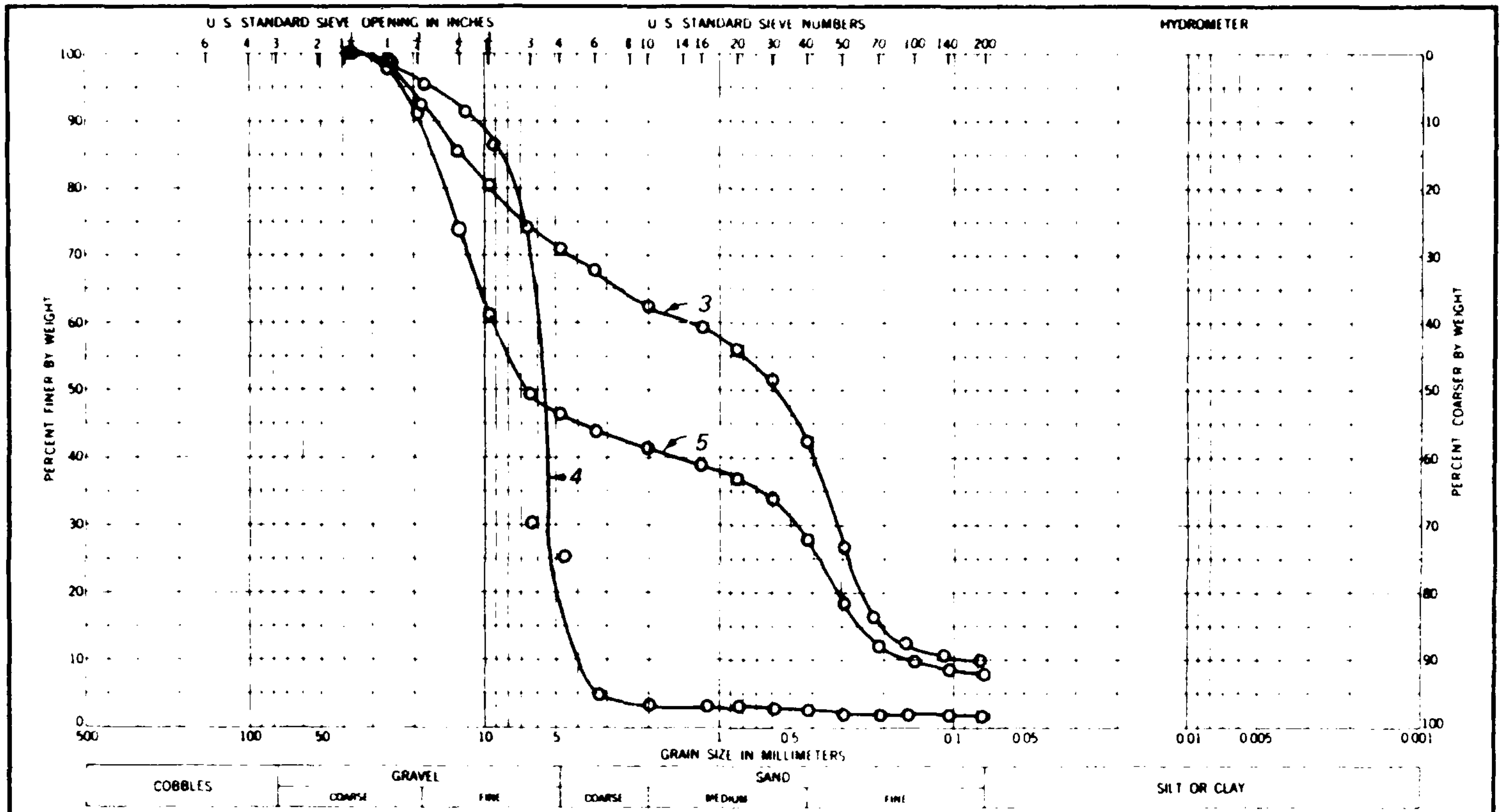
Figure 2. Gradation and classification data--soils 1 and 2



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI
3		CLAYEY SAND (SP-SC)		23	13	10
4		PEA GRAVEL (GP)				NP
5		CLAYEY GRAVEL (GP-GC)		26	11	15

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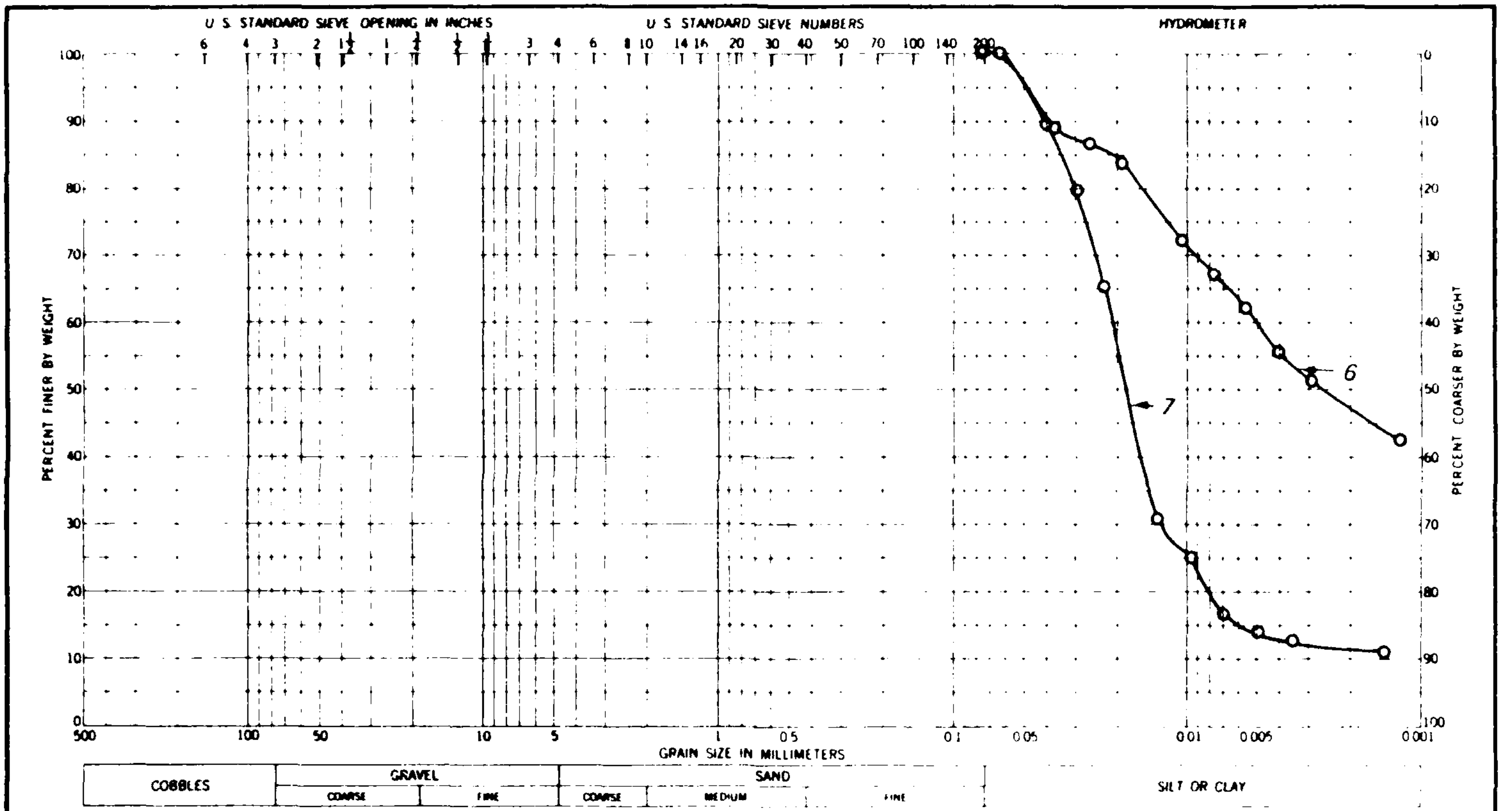
Figure 3. Gradation and classification data--soils 3, 4, and 5



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI
6		BUCKSHOT CLAY (CH)		64	20	44
7		SILTY CLAY (CL)		30	21	9

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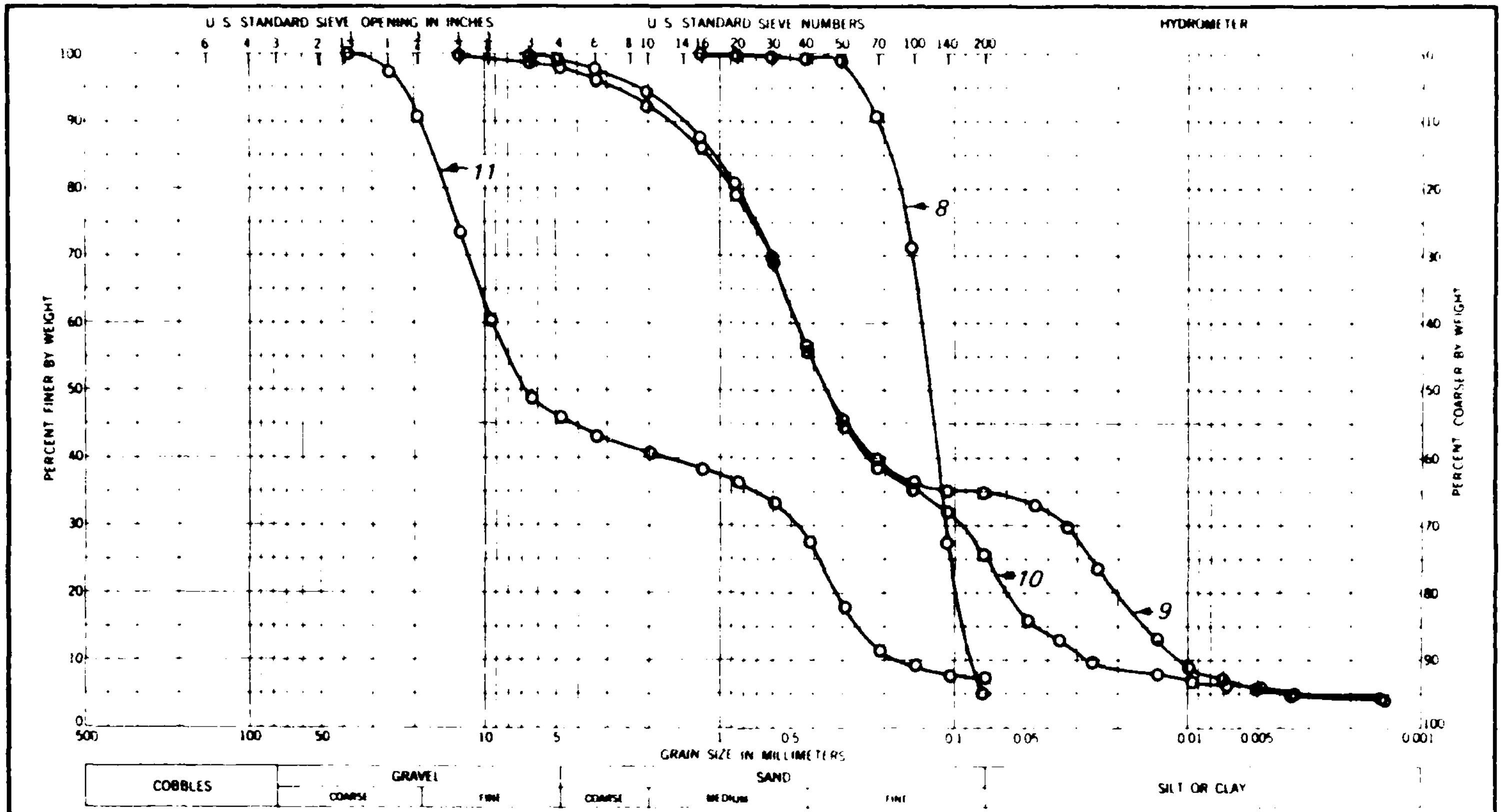
Figure 4. Gradation and classification data--soils 6 and 7



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI
8		YUMA SAND (SP-SM)		—	—	NP
9		SAND-BUCKSHOT BLEND (SM-SC)		26	16	6
10		RIVER SAND BLEND (SM)		17	16	1
11		CEMENT STABILIZED CLAYEY GRAVEL (GP-GC)		26	11	15

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Figure 5. Gradation and classification data--soils 8, 9, 10, and 11

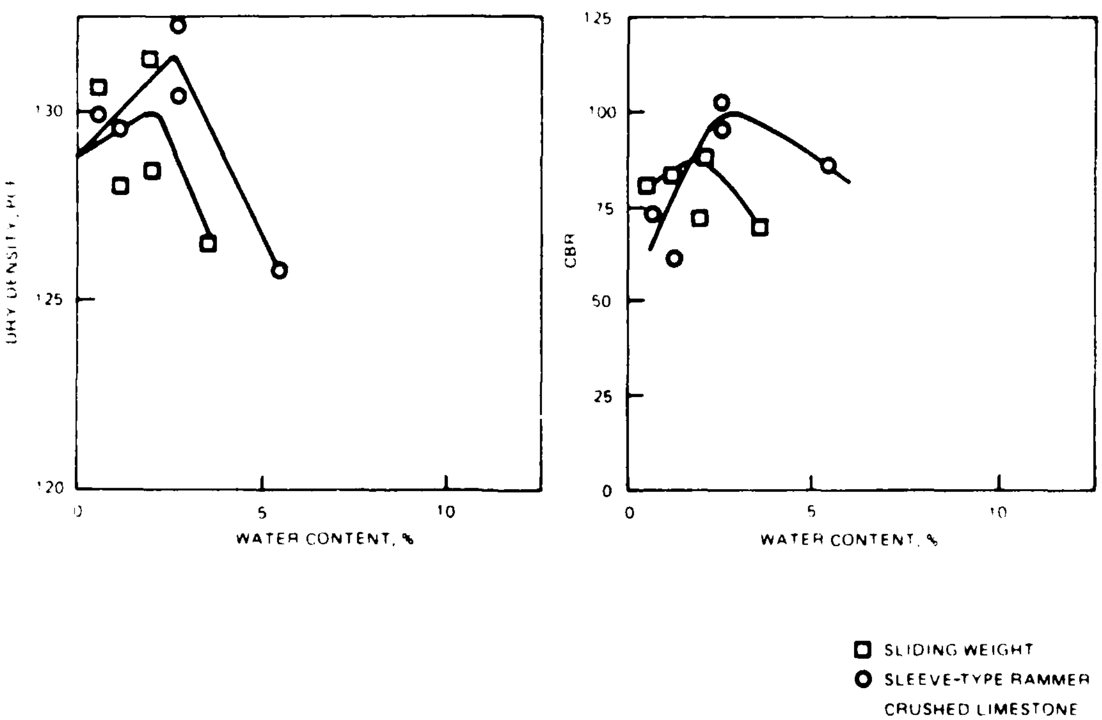


Figure 6. Dry density, water content, and CBR relations--soil 1

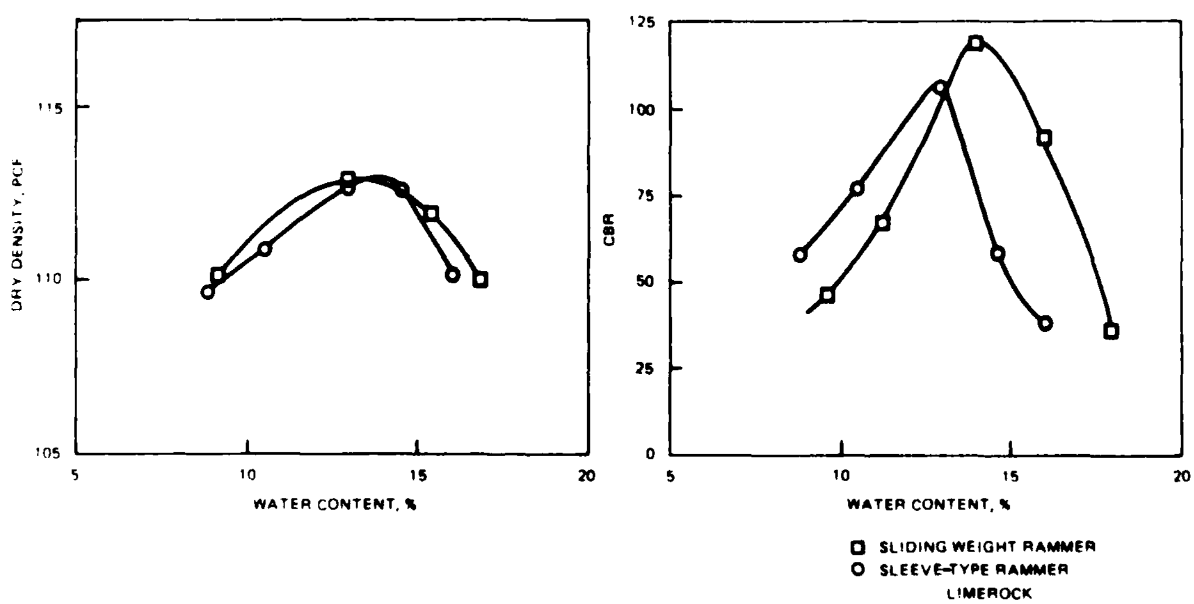


Figure 7. Dry density, water content, and CBR relations--soil 2

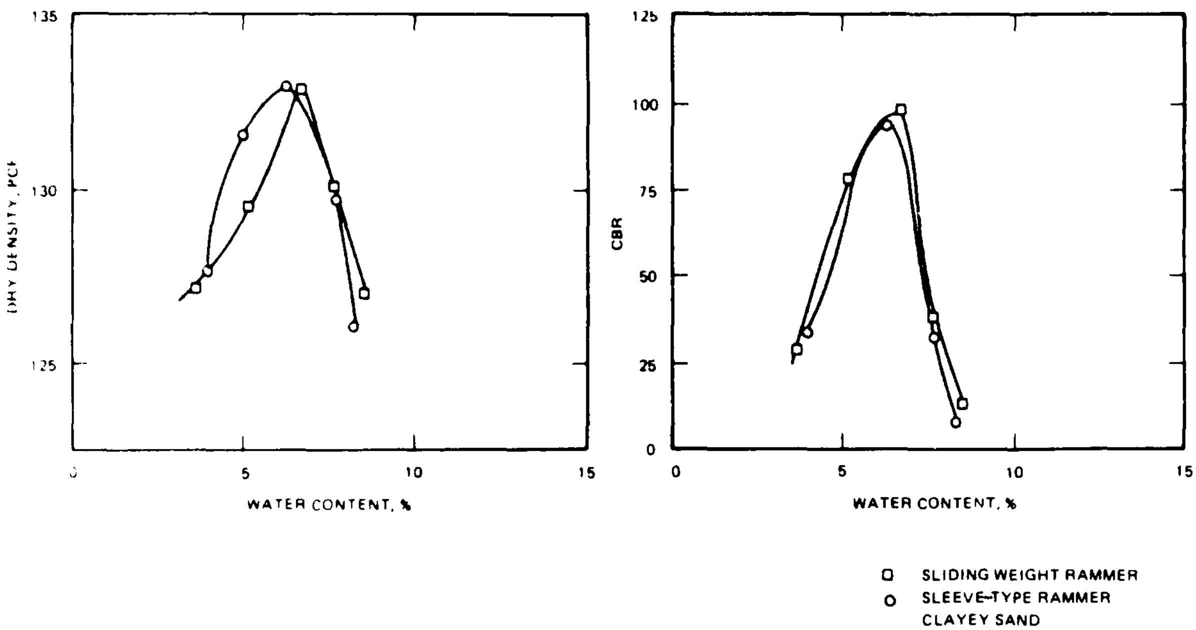


Figure 8. Dry density, water content, and CBR relations--soil 3

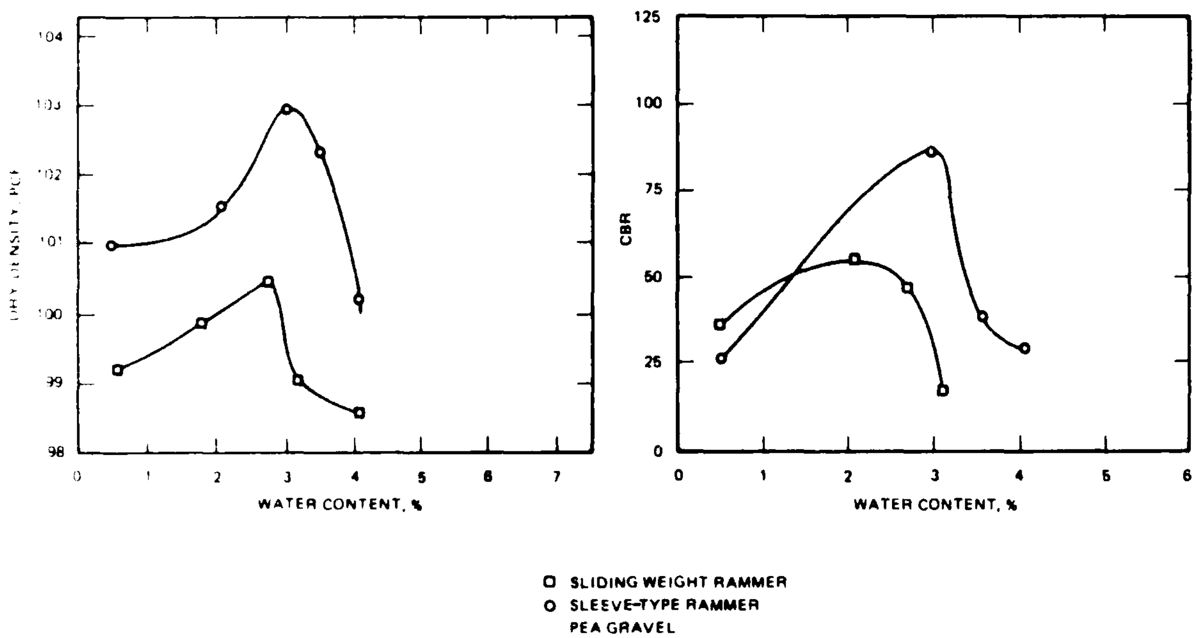


Figure 9. Dry density, water content, and CBR relations--soil 4

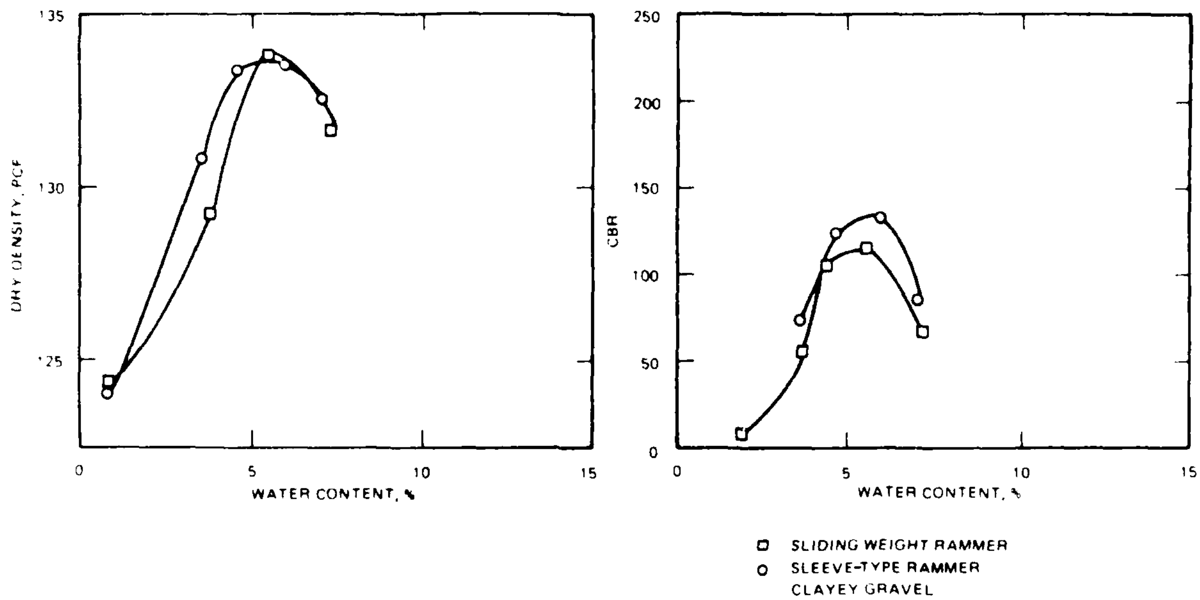


Figure 10. Dry density, water content, and CBR relations--soil 5

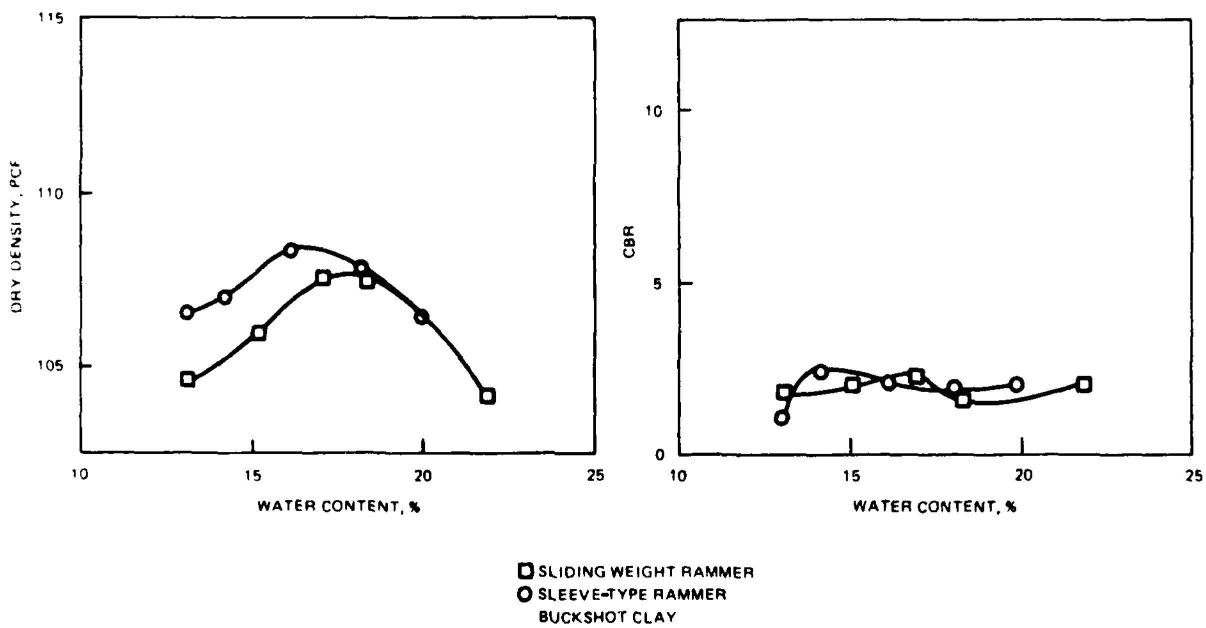


Figure 11. Dry density, water content, and CBR relations--soil 6

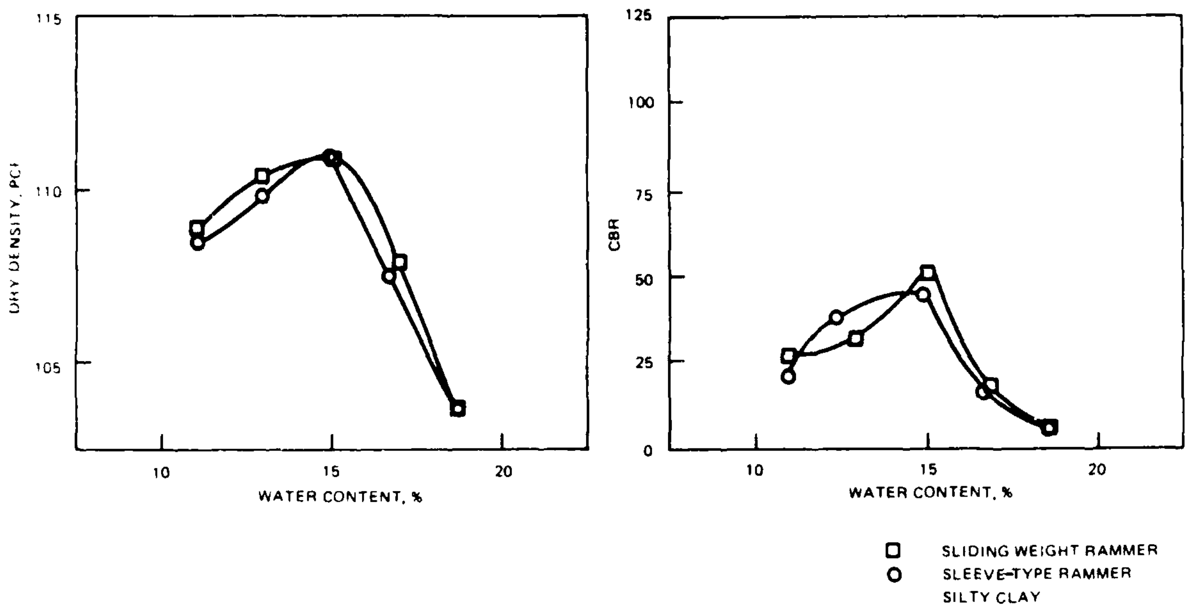


Figure 12. Dry density, water content, and CBR relations--soil 7

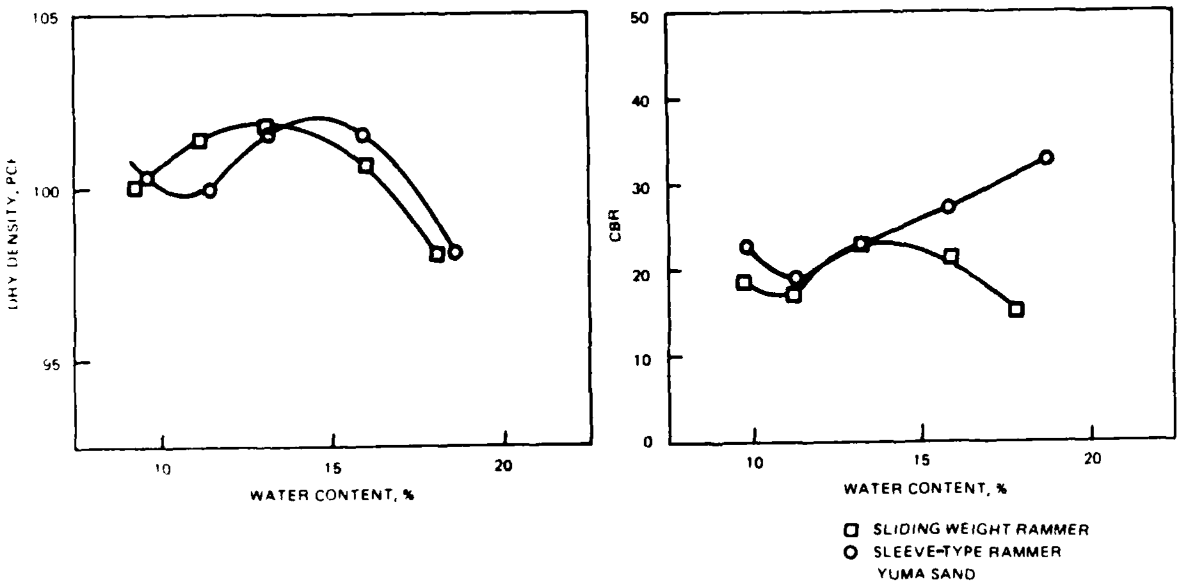


Figure 13. Dry density, water content, and CBR relations--soil 8

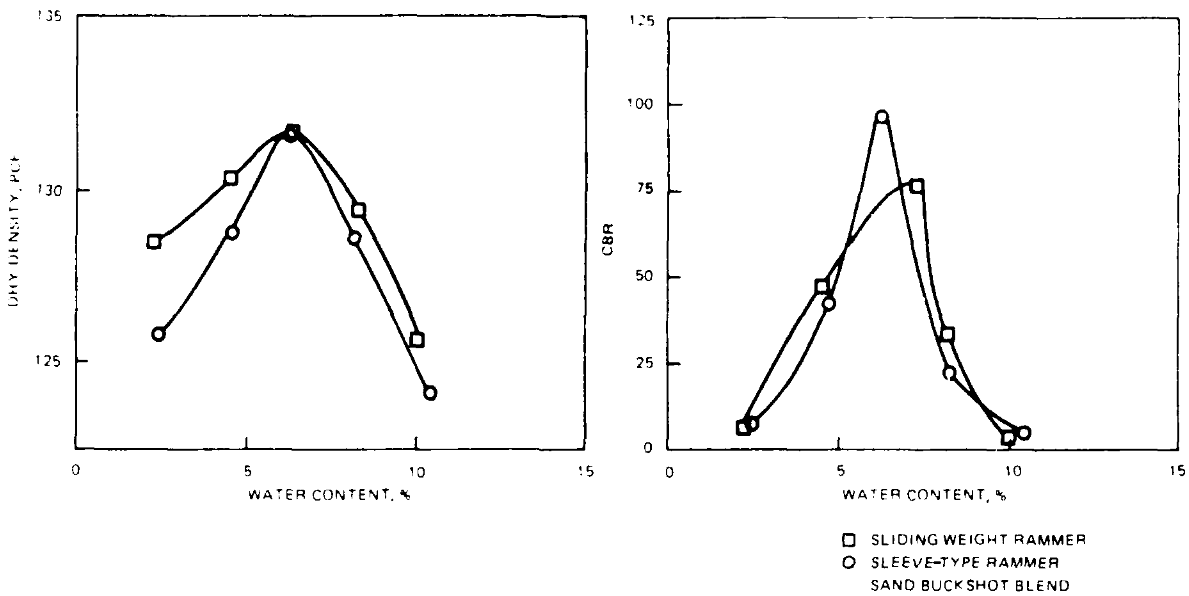


Figure 14. Dry density, water content, and CBR relations--soil 9

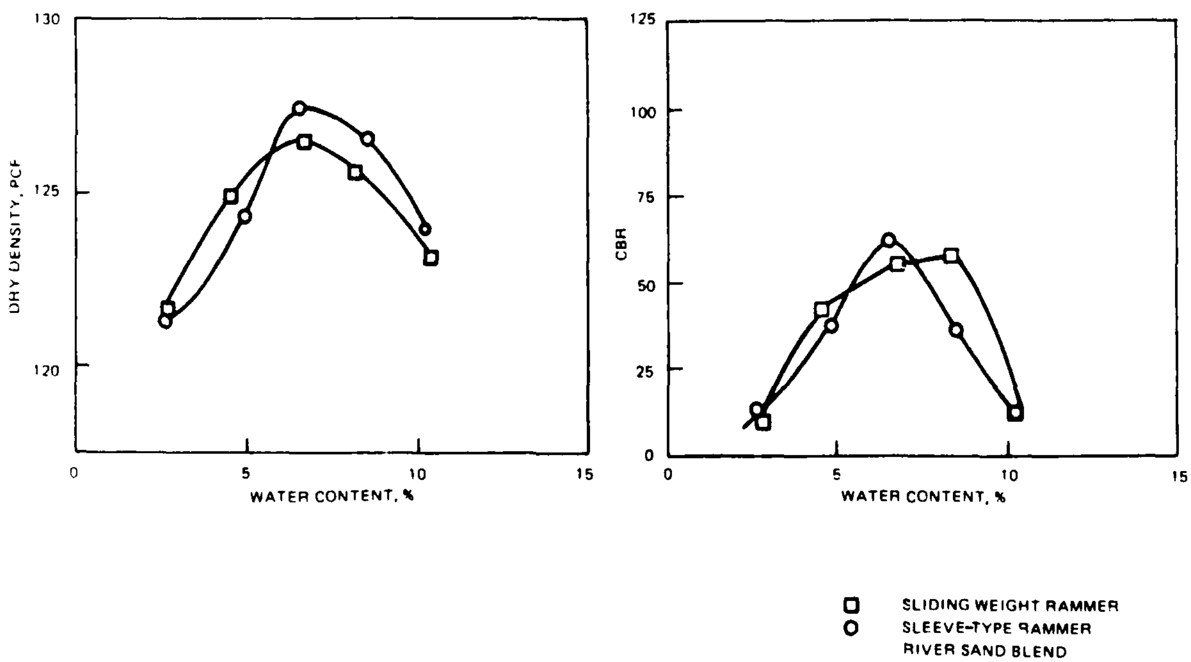


Figure 15. Dry density, water content, and CBR relations--soil 10

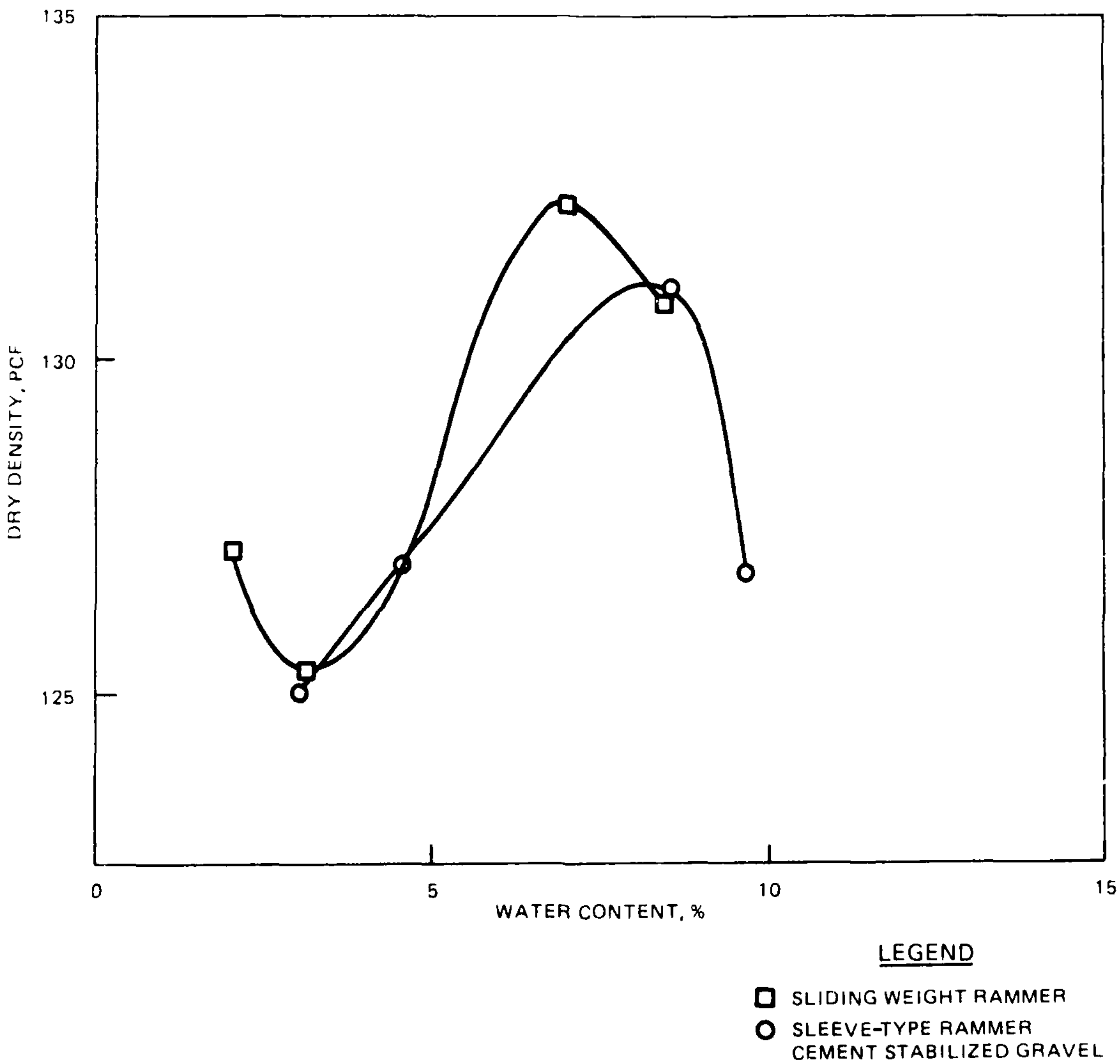
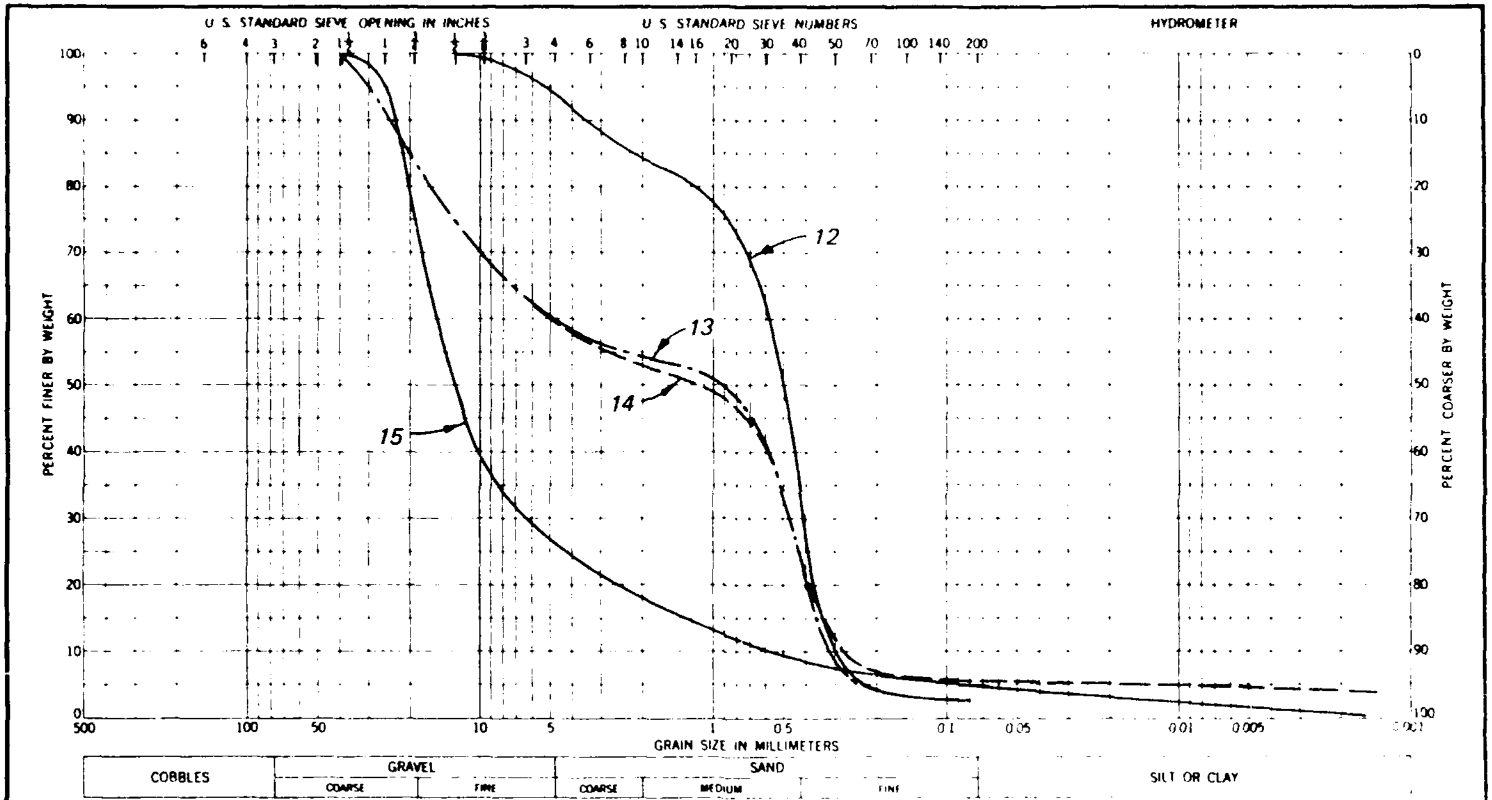


Figure 16. Dry density, water content, CBR relations--
no soil cement stabilized gravel



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI
12		CLEAN SAND (SP)				NP
13		GRAVELLY SAND (SP)				NP
14		GRAVELLY CLAYEY SAND (SP-SC)		28	11	17
15		LIMESTONE (GP)				NP

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Figure 17. Gradation and classification data--soils 12, 13, 14, and 15

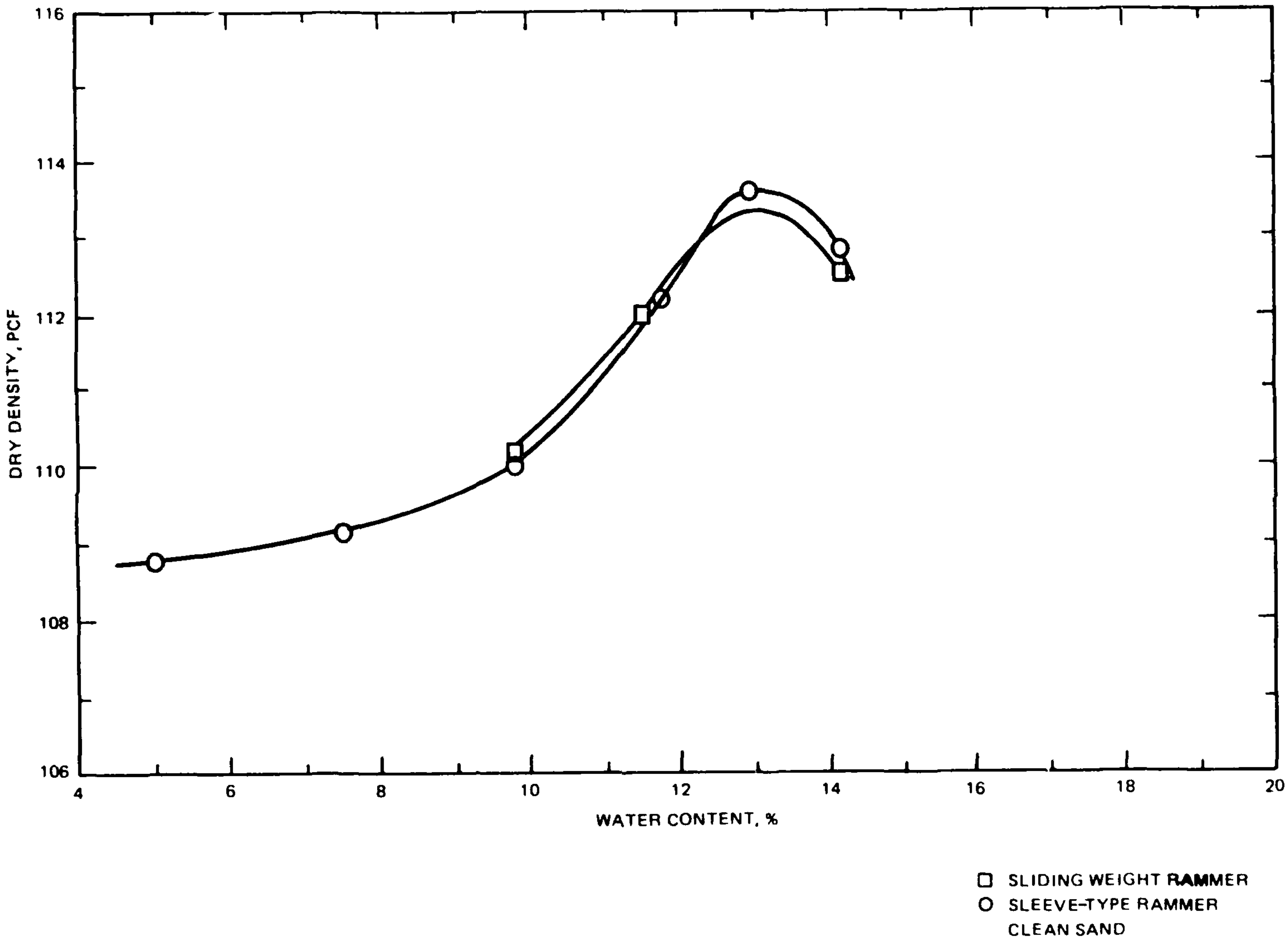

Figure 18. Dry density-water content relations--soil 12

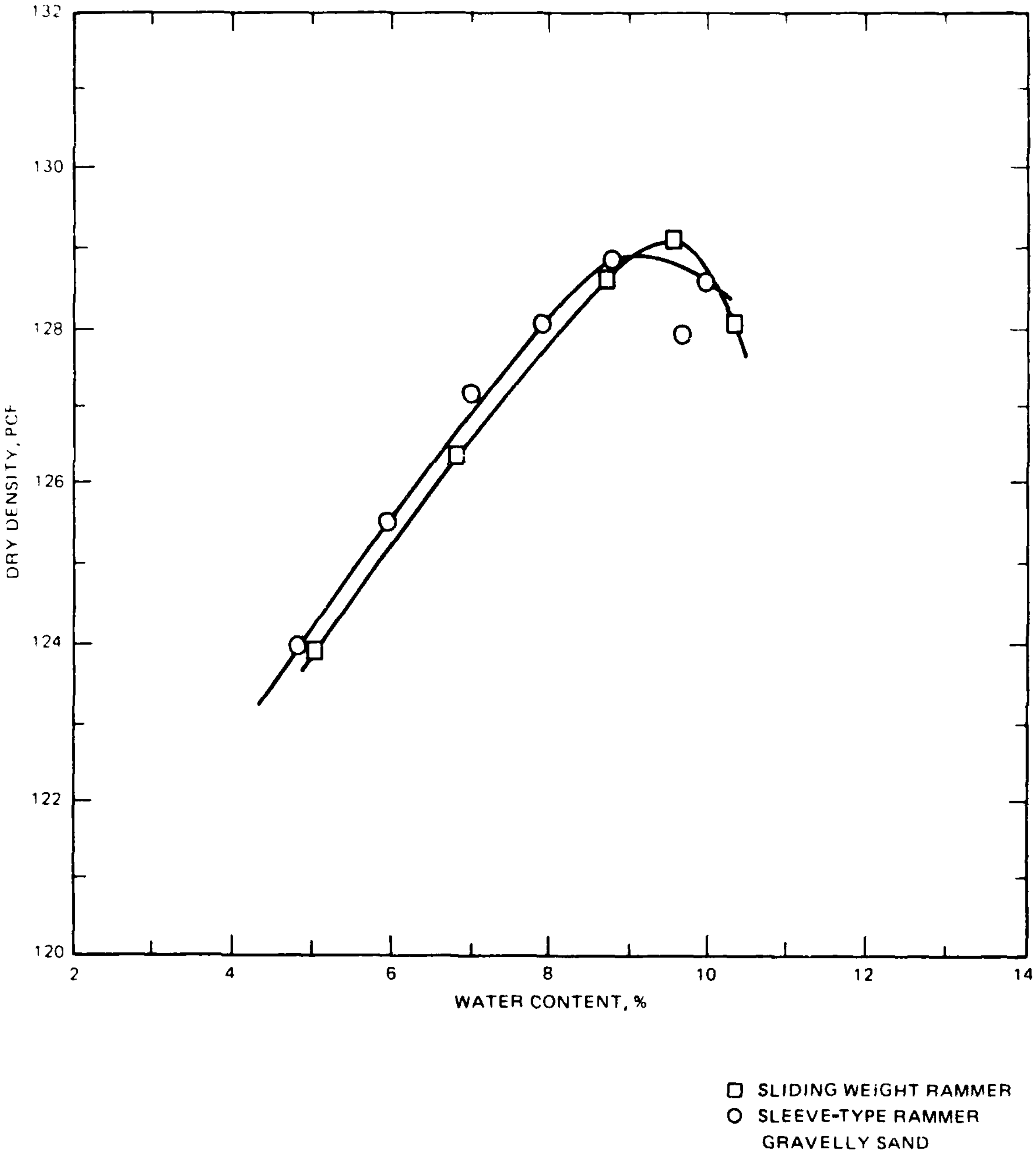

Figure 19. Dry density-water content relations--soil 13

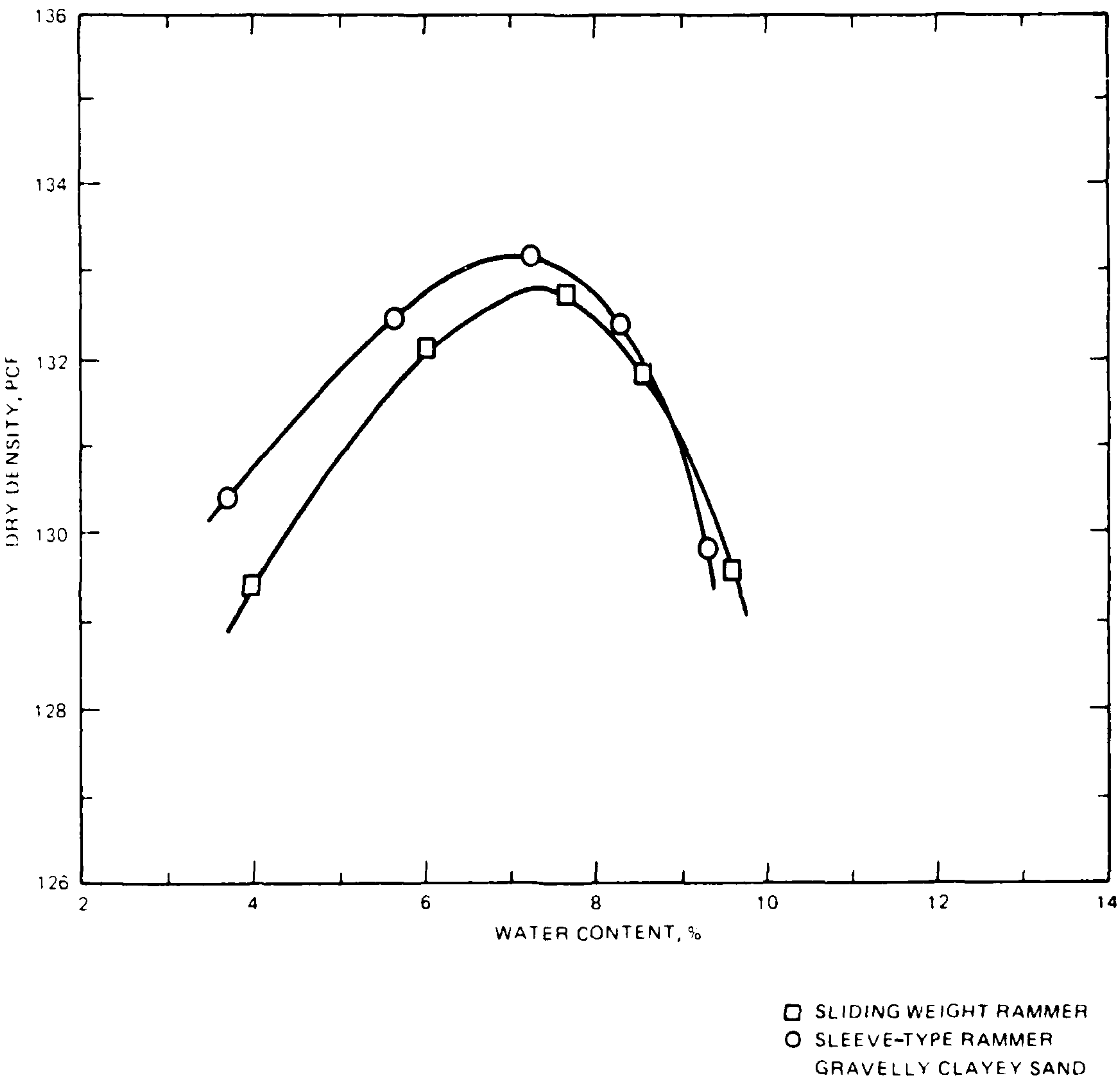

Figure 20. Dry density-water content relations-soil 14

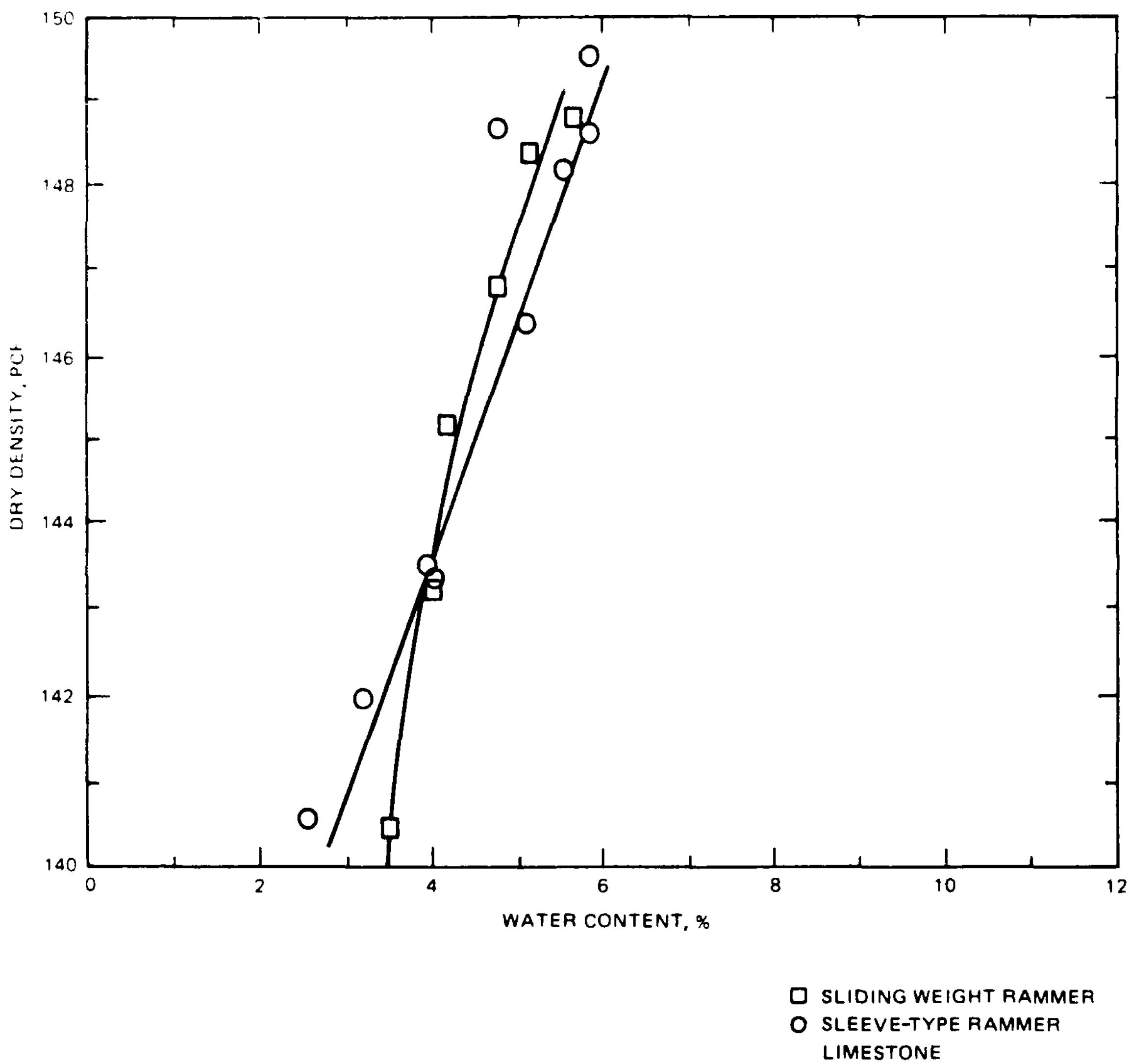

Figure 21. Dry density-water content relations--soil 15

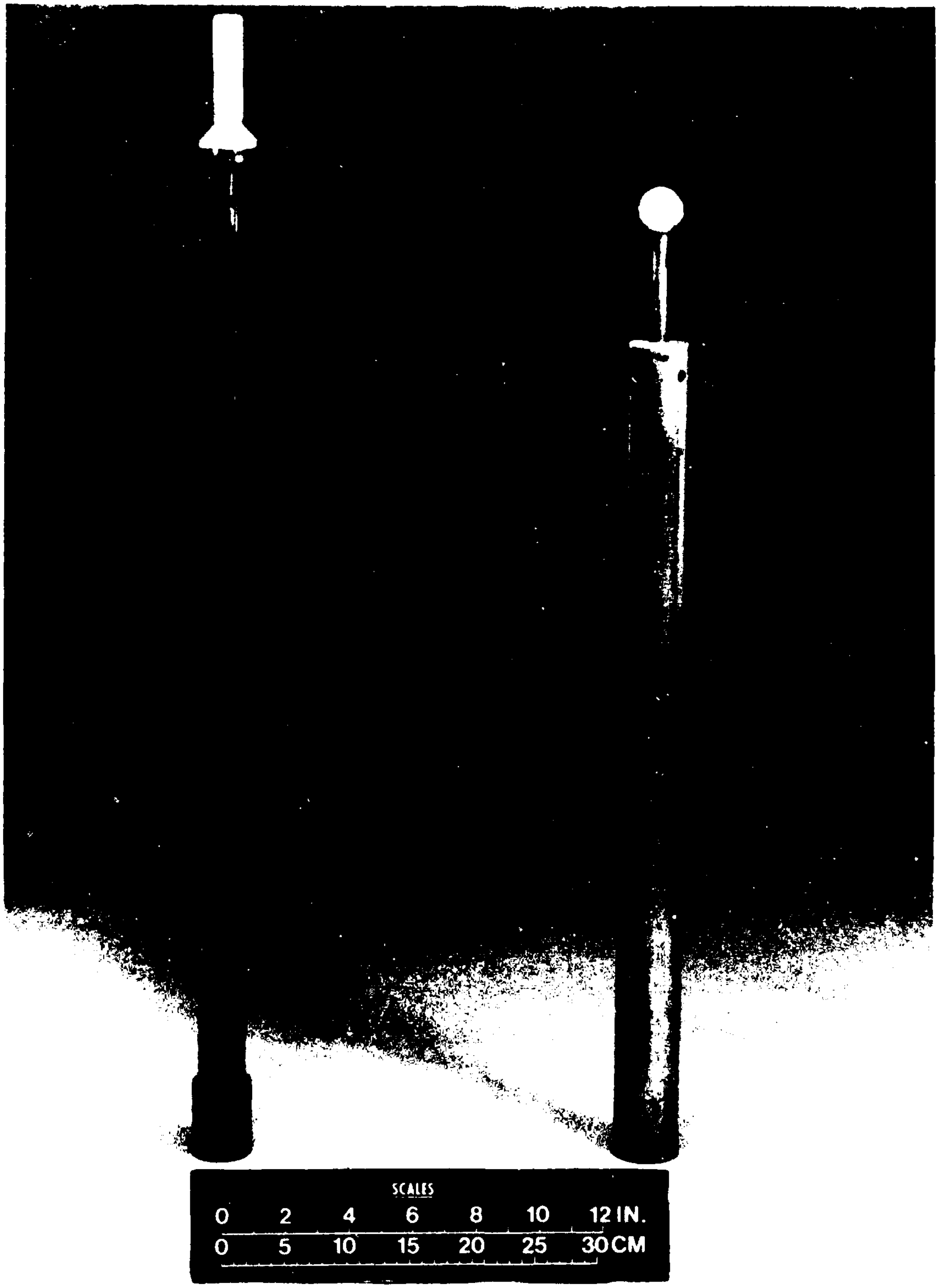

Photo 1. Ten-pound-compaction rammers--(a) sliding weight rammer (left) and (b) sleeve-type rammer (right)

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